CA Discussion Paper 1

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SEI STOCKHOLM ENVIRONMENT INSTITUTE

IWMI International Water Management Institute

COMPREHENSIVE Assessment of water management in agriculture

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The authors: Hector Galbraith, Ph.D. Galbraith Environmental Sciences LLC, 837, Camp Arden Road, Dummerston, VT05301; Priyanie Amerasinghe, Ph.D. International Water Management Institute; Annette Huber-Lee, Ph.D. Stockholm Environment Institute, Boston, Massachusetts.

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Summary

The purpose of this review was to evaluate the extent to which the current scientific literature allows us to determine and quantify the ecological costs and benefits of irrigated agriculture in wetland ecosystems of the developing countries, and to establish quantitative relationships between anthropogenic activities and ecological responses. The following are the main points that emerged:

- Irrigation or activities associated with agricultural irrigation can and do cause adverse impacts to wetland ecological resources ranging from localized and subtle, to long-distance and severe.

- Irrigation or activities associated with irrigation can also result in the creation or enhancement of important wetland ecological resources.

- Depending on the irrigation activity and scale, irrigated agriculture and ecological resources can sustainably coexist.

- The confounding effects of "natural" or other anthropogenic stressors are not often evaluated when the effects of irrigation on wetlands are being assessed, and it can be difficult to partition the effects due to irrigation.

- The potential long-term ecological benefits of water storage schemes are rarely investigated. Any measurement of impact usually stops once the project is implemented.

- Because of the above (bullets 4 and 5), "quantitative" information on the relationships between irrigated agricultural activity and ecological effects is sparse to non-existent. This severely impairs our ability to learn from previous failures or successes and, importantly, to design future activities and projects so as to minimize environmental impacts.

- If we are to minimize the potential for ecological injury and enhance the likelihood of benefits in future projects, it is crucial that the existing data base be enormously expanded. Specifically, we need to treat each new project and scheme as a "natural experiment" where the ecological resources and effects are quantified from before the project is implemented until long after implementation. Until this is accomplished, we run the risk of repeating the same mistakes that have been made in the past.

1. INTRODUCTION

The relationship between irrigated agriculture and its effects on wetland ecosystems has often been portrayed as one of a direct tradeoff between the human need for food versus nature. The reality, as revealed by this literature review, is much more complex, as both systems—human and nature—may be adaptive. Where nature might adapt automatically, such as a waterfowl adapting to paddy rice as a replacement for natural wetland habitat, humans too adapt consciously. For example, as humans have learned about the valuable services wetlands provide, the response has been to find ways to preserve and restore wetlands. This is relatively achievable in the developed countries, which has access to funds and the institutional and legal capacity to impose no loss of wetlands, but it is much more difficult in the developing countries where there are pressing needs for increased food production with the limited funds available. In such situations, nature may have to absorb the full costs of change, rather than humans modifying their expectations and requirements in the face of natural "needs." The goal of this literature review is to assess the knowledge available to developing countries in supporting decisions on alternative future strategies for irrigation implementation, and to assist in mitigating potential future ecological impacts of irrigation development. The focus of this review has been on developing countries because it is there, rather than in the developed countries, that the potential for large-scale adverse impacts is severe.

A brief discussion of the status and importance of both wetlands and irrigated agriculture is given in the next section. This is followed by a discussion of our approach in reviewing the literature. Finally, we present the results of our review in the form of six key conclusions that capture the state of knowledge of the effects of irrigated agriculture on wetland ecosystems in the developing countries. A set of recommendations for future research is given at the end of the paper.

2. BACKGROUND ON WETLANDS AND IRRIGATED AGRICULTURE

There is a long history of development leading to the complete destruction of massive areas of wetlands, particularly in the developed countries. In a generalized overview, the Organization for Economic Co-operation and Development (OECD 1996) stated:

> "Some estimates show that the world may have lost 50 percent of the wetlands that existed since 1900; whilst much of this occurred in the northern countries during the first 50 years of the century, increasing pressure for conversion to alternative land use has been put on tropical and sub-tropical wetlands since the 1950s.
>
> No figures are available for the extent of wetland loss worldwide, but drainage for agricultural production is the principal cause; by 1985 it was estimated that 56–65 percent of the available wetland had been drained for intensive agriculture in Europe and North America; the figures for tropical and subtropical regions were 27 percent for Asia, 6 percent for South America and 2 percent for Africa, making a total of 26 percent worldwide. Future predictions show the pressure to drain land for agriculture intensifying in these regions."

We begin this review with a definition of wetlands as well as some observations about the value or the services wetlands provide to human society. Agriculture, and irrigated agriculture in particular, have been critical to supplying the food needs of an ever increasing human population. Clearly we cannot eliminate irrigated agriculture. The road ahead must include ways of farming that recognize the value of wetlands.

2.1 Wetlands

The global wetland area is generally estimated to be 7 to 9 million km^2 (4–6 percent of the land surface of the Earth)—(Mitsch and Gosselink 2000). While there are many definitions to the term "wetland" many would agree that these are areas with high water tables contributing to a specific ecology. The most broadly accepted definition of wetlands is: "Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt including areas of marine water, the depth of which at low tide does not exceed 6 meters"(Ramsar Convention 1971; Articles 1.1 and 2.1).

Wetlands are increasingly gaining global attention, bringing together many scientists from different disciplines to study these unique ecosystems. One example of such attention is the Ramsar Convention on Wetlands, adopted in 1971 and as of December 2002 has 1230 wetland sites distributed in six regions (Europe, Asia, Africa, Neotropics, Oceania and North America) recognized as wetlands of international importance (Wetlands International Ramsar sites database, 2002). However, there are likely to be many more wetlands to be identified and recorded as many countries have only recently begun identifying important wetlands.

The functional value of wetlands depends on their size and placement within the landscape, as well as their relationship to adjacent water areas. Wetlands can be natural or artificial or mixtures of both. There is general agreement that the existence of wetlands is due to specific hydrology, soil type, and vegetation and animal communities, and that their functions depend on the context of their relative placement within the ecosystem. Some of the services wetlands provide include:

- Habitat for aquatic birds, other animals and plants, fish and shell fish production;
- Biodiversity;
- Food production;
- Water storage, including mitigating the effects of floods and droughts;
- Groundwater recharge;
- Shoreline stabilization and storm protection;
- Water purification;
- Nutrient cycling;
- Sediment retention and export;
- Recreation and tourism;
- Climate change mitigation;
- Timber production;
- Education and research; and
- Aesthetic and cultural value.

Few attempts have been made to calculate the economic value of the goods and services provided by wetlands. Although the accuracy and precision of these attempts may be debatable, they have merit in that they draw attention to and emphasize their enormous economic importance. Previous estimates include: between US$8,977 and US$17,000 (1983) for the goods and services provided by each acre of Louisiana wetlands (Costanza et al. 1989), and between US$19 million and US$70 million per year for a 45–mile stretch of the Platte River, Colorado (Loomis et al. 2000). In the developing countries, the existence and functioning of wetlands can be crucial for adjacent agricultural and extractive economies (e.g., Hollis et al. 1993b).

While the functional and economic values of wetlands are increasingly recognized, development projects continue to lead directly or indirectly to their loss. As presented in the following section, irrigated agriculture has been destructive in the past, and has the potential to continue to do so in the future unless better management processes are established in the developing countries.

2.2 Irrigated Agriculture

Irrigation has been practiced for at least 4,000 years, primarily because it allows for increased productivity through more optimal timing of water application. More recently, irrigated agriculture in combination with improved crop varieties and chemical inputs has led to 24 percent more food per person between 1961 and 1997, despite the population increase (Pilot Analysis of Global Ecosystems 2000). In addition to increase food security, there is a net increase in economic gains to farmers.

It is estimated that around 5 percent of agricultural land globally (264 million ha) is irrigated, with South Asia (35%), Southeast Asia (15%) and East Asia (7%) showing a high dependency on irrigation. China and India represent 39 percent of the global irrigated area and Western Europe and United States have 13 percent, while sub-Saharan Africa and Oceania have less than 1 percent of their agricultural land irrigated (PAGE and Wood 2000). Irrigation accounts for approximately 70 percent of the water withdrawn from freshwater systems for human use. Only 30–60 percent is subsequently used downstream, making irrigation the largest net user of freshwater. Estimates also show that the share of cropland that is irrigated has grown by 72 percent from 1966–1996. Developing countries tend to have scarce water resources and relatively larger agricultural demands; and as such will have greater water extractions, which in turn can have greater impacts on associated wetlands (Pilot Analysis of Global Ecosystems 2000).

While environmental impacts have been recognized as important in assessing agricultural projects, and assessment processes exist, active monitoring against baseline pre-project conditions have not kept pace with developments in productivity. Some aspects often regarded as important in assessment are hydrology, water and air quality, soil properties, erosion and sedimentation, biological and ecological change, socio-economic impacts, ecological imbalances and human health (FAO 1995), although all aspects are not often covered for a given project, due to external factors affecting project implementation. The classic example is that of dams, which have been constructed to control the natural variations of the hydrological cycles, so that the water is made available on demand for agriculture. Often the effects of flooding downstream and their benefits were not contemplated. The importance of natural flooding to fisheries and recession agriculture and groundwater recharge have been realized only recently (Acreman 1996).

Some of the established effects of agriculture on wetlands include:

- Direct loss of wetlands due to draining and conversion to agricultural land;
- Indirect loss of wetlands area due to water withdrawal from rivers and streams for irrigation;
- Loss of wetland area and function due to damming for water storage;
- Loss of seasonal wetlands due to changed hydrologic cycle from water storage;
- Loss of wetland function due to salinization, sediment deposition, erosion, eutrophication;
- Pollution from use of pesticides and other chemicals; and
- Creation of wetlands

Examples of many of these effects are described with specific examples in subsequent sections of this review.

3. APPROACH

Relevant documents were identified by first conducting a literature search under the keywords: irrigation and wetlands. This computerized search identified an initial total of 1096 references. The majority of these were rejected from further consideration either because: a) they did not apply to developing countries; b) they were obviously journalistic or nonscientific in nature; or c) they were derived from primary studies, the results of which were reported in original documents that could be obtained. This left a total of approximately 180 reports that were potentially useful. Hard copies of these reports were obtained from various libraries, or by contacting the authors directly. Once obtained, the reference list for each report was examined to determine if additional and pertinent reports that had not been found in the original search were available. These were then obtained, whenever possible.

An additional search procedure was to contact known participants in the field and ask them to identify documents and/or data sets that they considered important. The individuals who were contacted and their affiliations are aknowledged in the copyright page.

A total of approximately 200 documents were obtained and reviewed. Of these, 37 contained information pertinent to our study. These are listed in the References List in section 7, with notes on their findings in Appendix A to this paper.

3.1 Biases

We have reviewed only documents that apply to developing countries; no thorough or systematic review of the developed country literature has yet been performed. This is important, as it may introduce a bias into our results: most of the practical attempts to integrate agricultural and ecological concerns have taken place in the developed countries, and most of studies of the ecological benefits of irrigation have also been carried out there (e.g., the wildlife resources associated with the irrigated farmland in the Central Valley of California, or the rice fields of Louisiana). On the other hand, costs, rather than benefits, have been the main foci of studies in the developing countries.

Thus, focusing entirely on the information of developing countries may bias the results of any review toward the ecological costs of irrigation and downplay the potential benefits.

3.2 Questions for the Review

Within the general charge of reviewing the scientific and "gray" literature to evaluate the extent to which irrigation has been shown to affect wetland ecosystems in developing countries, we concentrated on providing answers that may be useful in developing alternative future strategies for irrigation implementation, and assisting in mitigating potential future ecological impacts. Each reviewed document was evaluated in terms of the information that it provided pursuant to eight questions:

1. What were the ecological effects that were caused by irrigation and could they be distinguished from effects due to other anthropogenic or natural stressors (i.e., how confident can we be that the observed effects were due to agricultural water use?)

2. Did the project described result only in ecological costs, or were there also benefits?

3. Are there taxonomic relationships between costs/benefits and project types, scales, and management regimes?

4. Do the data and information presented in the paper facilitate the identification of quantitative relationships between intensity of use (e.g., amount of withdrawal) and degree of ecosystem impact?

5. Which components/activities of the project contributed most to the costs and/or benefits? And did the project find ways to mitigate or enhance certain effects?

6. Did the resulting end-use of the irrigation water (i.e., the crop type) affect the costs and/or benefits?

7. Did the surrounding habitat matrix (i.e., arid versus non-arid) matter in whether costs or benefits were incurred?

8. Is it possible to identify indicators of ecological costs and benefits that could be used either at small or large spatial scales, or at both?

To the extent possible we attempted to focus on all potential types of impacts of irrigation on wetlands. These include both the effects of water withdrawals upstream of the wetland, and irrigation activities within the wetland, itself.

Much pertinent information is contained in gray literature sources that are difficult to identify and locate. Thus, the process of reviewing all potentially relevant documents is not yet complete. Indeed, it is unlikely to ever be so. However, we believe that the most important documents have been reviewed and the main results have already emerged (particularly in the areas of data gaps and information needs). We anticipate that these results will contribute to the knowledge base of IWMI's Comprehensive Assessment.

4. RESULTS

Six main results have emerged from the literature review:

1. Irrigation or activities associated with agricultural irrigation can and do cause adverse impacts to wetland ecological resources ranging from localized and subtle, to long-distance and severe.

2. Irrigation or activities associated with irrigation can also result in the creation or enhancement of important wetland ecological resources.

3. Depending on the irrigation activity and scale, irrigated agriculture and ecological resources can coexist in potentially sustainable fashions.

4. The confounding effects of "natural" or other anthropogenic stressors are not often evaluated when the effects of irrigation on wetlands are being assessed.

5. The potential long-term ecological benefits of water storage schemes are rarely investigated. Any measurement of impact usually stops once the project is implemented.

6. Because of the above (4 and 5), "quantitative" information on the relationships between irrigated agricultural activity and ecological effects is sparse to non-existent. This severely impairs our ability to learn from previous failures or successes and, importantly, to design future activities and projects so as to minimize environmental impacts.

Each of these conclusions is examined in greater detail below.

4.1 Irrigation or activities associated with irrigation can and do cause adverse effects to wetland ecosystems.

Irrigation schemes or water diversions for irrigation have undoubtedly caused adverse effects to wetland ecosystems. At their most severe, these effects have included the submersion of wetlands, or their replacement by upland vegetation communities (or by essentially unvegetated land in the case of the Aral Sea), with consequent effects on the biota that depend on these wetlands and the services that humans hitherto derived from the systems. Documented examples of these extreme cases include the Aral Sea literature (Kotlyakov 1991; Micklin 1988; Precoda 1991), the impacts of water diversions on wetlands in the Colorado River delta in Mexico (Glenn et al. 2001), impacts of dam construction on the floodplain of the Longone and Benue Rivers in Cameroon (Scholte et al. 2000; Tchamba et al. 1995; Drijver and Marchand 1985; Wesseling and Drijver, 1993), and similarly for the Senegal Delta (Drijver and Marchand 1985; Vinke 1996), and impacts on the Hadejia-Nguru wetland complex, Nigeria (Lemly et al. 2000). All of these resulted in major impacts to downstream wetland ecosystems, including dewatering and drying (Aral Sea, Logone River, and Colorado River), and submersion and replacement by aquatic communities, for example, the Nanni Swamp in Surinam (van Maren 1994).

The ecological impacts of irrigation or water diversions for irrigation can occur a short distance from the dam or irrigation site, or many miles downstream. Examples of the latter include the construction of the High Dam at Aswan, which, by reducing sediment transport, is contributing to the erosion of wetlands in the Nile Delta 800 km downstream (Penvenne 1996). Also, the size of the marine harvest of prawns off the coast of Mozambique is positively correlated with the flow entering the sea from the Zambezi River (GammelsrØd 1996). Recent declines in marine prawn populations and impacts to the commercial prawn fishery have been ascribed to reduced flows from the Zambezi River due to barrages and dams in Mozambique (GammelsrØd 1996). The damming of the Indus in Pakistan, like the Nile example, has also reduced sediment transport with subsequent die-off of mangrove forest communities in the downstream delta (Meynell and Qureshi 1995).

When viewed against the backdrop of wetland hydrologic needs, the ecological impacts caused by schemes such as the Aral Sea diversions, the damming of the Indus, or the Kano River Irrigation Project are not unexpected. They are largely a function of the scale of water diversion. Large projects that divert the majority of the flow of the feeder streams will "necessarily" result in large impacts to the associated wetlands.

Although no quantitative relationships have been established, and the resilience of any particular wetland ecosystem will vary depending on other anthropogenic and natural stresses, it may be likely that relatively small percent diversions (10% or less?) may be ecologically sustainable in some wetlands (though perhaps not all), whereas larger diversions as have occurred in many schemes, are more likely than not to be unsustainable. Also, it is at least possible that the relationship between the scale of the withdrawal or diversion and the ecological impact may not be linear. The first quartile of the flow diverted may have much less effect than (say) the second or third. This, if so, is both good and bad news: up to a certain limit, withdrawals may be sustainable; however, exceeding that limit might result in disproportionate, unexpected, and potentially irreversible effects. Also, the ability of a wetland to withstand a level of diversion may be partly a function of the intrinsic variability of the wetland itself: wetlands that go through marked natural cycles of water inflow may be more resilient than more stable wetlands (since the biota of the former may be better adapted to water shortage). However, given that so little quantitative information concerning ecological impacts has been generated by past irrigation projects, the above considerations are largely speculative.

Unfortunately, too few rigorous studies have been performed to determine the levels of withdrawals that may be adequately protective of the environment. Nevertheless, this is the crucial question determining the likelihood of coexistence of ecological resources and irrigated agriculture. Assuming that we can define an "acceptable" level of impact, how much water can be diverted and used without the risk of unacceptable ecological impacts? This question automatically focuses attention on the resilience of wetland ecosystems (i.e., the ability of wetland systems to resist and recover from a stressor). Resilience will be a function of a number of important site-specific factors, including the type of wetland and its intrinsic robustness, and the existing level of stress (natural and anthropogenic). Unfortunately, while resilience is an important and much-discussed ecological principle, how to measure it has not received enough attention. By failing to monitor the ecological consequences of the implementation of irrigation projects, we have lost an important opportunity to understand the relationships between levels of stress (e.g., water withdrawals) and ecosystem resilience and impacts.

Apart from failing to realize the ecological consequences of the scale of diversions (or realizing, but ignoring them), the other main problem that has contributed to impacts is a failure to plan at the level of the watershed or larger scale. Were the effects of the Aswan Dam on the Nile Delta 800 km away or the effects of the Zambezi flows on the marine prawn fishery adequately considered when the potential impacts of the dams were being evaluated? Obviously, the extent of the environmental disaster caused by the Aral Sea scheme came as a surprise to planners who focused at the local or, at best, the regional level.

Almost all of the literature reviewed concerned situations in which upstream withdrawals had affected downstream wetlands. However, in some cases, extractions may take place in the wetland itself, to irrigate either surrounding upland areas or other parts of the same wetland (the situation that may pertain in many Southern African dambos). To what extent do these activities have similar effects as upstream extractions? If the water being extracted from the wetland is for irrigation of adjacent uplands, but return flows are large, the impacts may be less severe. And if the water is being shunted around different parts of the wetland (rather than being moved to non-wetland habitats), the consequences may also be less severe. In these situations, a number of important site-specific considerations arise: what is the loss to evaporation of the return flow? To what extent are different parts of the same wetland ecosystem functionally equivalent and does removing (or returning) water to one or more parts preserve the whole wetland ecosystem? Unfortunately we do not yet have information or data that could be used to answer these important questions.

In addition to the installation of new dams and irrigation schemes, changing traditional management practices at long-established projects can also result in ecological impacts. Switching from ditch-fed irrigation to concrete channels and metal pipes in the Kanto Plain rice paddies in Japan resulted in population reductions in two species of frogs that depended for their spawning habitat on the traditional, "inefficient" ditches that helped create pools of standing water during the frog spawning season (Fujioka and Lane 1997).

Water withdrawals for irrigation in some cases can act to exacerbate the effects of other stressors on the wetland ecosystems, resulting in effects that exceed those that would be expected from dewatering, alone. Lake Kus in western Turkey is under stress from a growing use of the lake by the local human population. One of these stresses is the increasing pollution of the lake by organic materials. This, in conjunction with dewatering for irrigation, has resulted in the increasing eutrophication of the lake and changes in the aquatic biota toward an assemblage more characteristic of nutrient rich systems (Altinsacli and Griffiths 2001). Wildlife responses to the implementation of irrigation schemes can, in turn, result in stress to wetlands. In and around the Waza National Park in Cameroon, dewatering of the Logone River has resulted in the loss of prime grazing habitat for wildlife. Populations of some ungulates such as reedbuck and kob have been lost or severely reduced. Elephants have responded differently: they have been displaced from their traditional areas, resulting in damage to wetland habitats (and more frequent interactions with farmers)—(Tchamba, et al. 1995).

4.2 Irrigation or activities associated with irrigation can result in the creation or enhancement of important wetland ecological resources.

Few published examples have been found where water storage for irrigation unambiguously created valuable wetland habitat in the developing countries. This does not mean that such benefits do not occur (see the discussion in Section 2.1 of the bias inherent in focusing only on developing world studies). Water storage tanks in Sri Lanka undoubtedly provide functional and valuable habitat for wetland organisms. Observations over only a few hours at one such tank during December 2000 resulted in 22 species of herons, shorebirds and waterfowl being recorded (Hector Galbraith unpublished data). Tanks elsewhere in Sri Lanka are known to support a similar diversity of wetland birds (Galbraith unpublished data), which matches that found on natural wetlands in Sri Lanka and Asia.

While there are few studies of such benefits in the developing countries, data from the developed countries give some indication of types and scope of benefits that may accrue: for example, the rice fields in the Central Valley of California and in Louisiana, USA, provide important habitat for waterbirds and shorebirds (Day and Colwell 1998; Remsen et al. 1991, respectively). The populations of birds that these areas support are likely to be of at least national importance. Similarly in Mediterranean countries, rice agriculture has created internationally important habitat for wading birds (Fasola and Ruiz, 1996). In the UK there are over 500 reservoirs. These provide habitat for birds and other water-associated organisms and are particularly valuable because of the extensive areas of wetland that have been drained. The general importance of these reservoirs for wildlife is indicated by the designation of 174 as Sites of Special Scientific Interest (Moore and Driver 1989). It is likely that such benefits to birds and mammals may be greater in otherwise arid areas, rather than in areas where natural wetlands are more plentiful.

By its nature, rice farming is most likely among the various uses to which irrigation water is applied to result in new valuable wetland habitats. The instances cited above lend support to this. However, as yet, these ecological benefits have not been catalogued in any systematic way.

4.3 Wetland ecological resources and irrigated agriculture may coexist under certain circumstances

The examples in Section 3.1 notwithstanding, not all irrigation schemes have adversely affected associated wetland ecosystems. Examples may include the cultivation of dambos (shallow, channel-less, seasonally inundated depressions) in southern Africa, where up to 30 percent of dambo area may be irrigated without obvious adverse ecological impacts (Faulkner and Lambert 1991). However, since this conclusion has not yet been rigorously tested through ecological analysis, this conclusion must remain speculative. Also, Lankford and Franks (2000) argue that coexistence of wetlands and irrigation for rice is possible in at least some parts of Tanzania, providing that the spatial and temporal variability in the water needs of the wetland are understood and accommodated into the agricultural planning. The key in this case is flexibility in being able to change seasonal allocations of water based on flow data; during dry years, a greater proportion of the flow may be allocated to protect wetland core areas. During wet years, irrigation may be increased without jeopardizing the wetland ecosystem. In both cases, adverse impacts are avoided by allocating an adequate amount of water to the wetland and by planning for the entire watershed.

A modeling study conducted by De Voogt et al. (2000) predicted that for the important Turkish wetland bird breeding site, Kus Cenneti, irrigated agriculture and wetland ecosystem resources could coexist. Currently the wetland is being adversely affected by low flows due to diversions during the bird breeding season (also the main irrigation period). De Voogt et al. (2000) estimate that the wetlands could be maintained by allocating river water flow to them. This would result in a predicted loss of yield in the agricultural system of a few percent during dry years and no loss in wet years. In this model, the water needs of the wetland were not estimated in great detail. It is possible that if temporal and spatial estimates of nature's "demand" were studied more closely, the integration of agriculture and wetland values could be made more compatible and the small predicted yield losses reduced even further. Also, the crops that are currently grown in the area are "thirsty"—cotton and grapes. Institutional encouragement to switch to other crop types might make enough water available for both the farmers and the wetlands.

4.4 Confounding effects of natural and other anthropogenic stressors

Natural factors such as drought may confound the evaluation of the ecological impacts of water withdrawal and use for irrigation. An example is the ecological impact to the Hadejia-Nguru wetland complex in Nigeria (Hollis et al. 1993a; Lemly et al. 2000). The latter study reports declines in the avian populations using the area and implicates water storage schemes as the main cause. However, this area suffered severe droughts during the 1980s and 1990s when precipitation was markedly reduced (Hollis et al. 1993a), after many years of above average rainfall in the 1950s, 1960s, and 1970s. The extent to which these natural events contributed to the waterbird population reductions has not been assessed. In the Logone floodplain in Cameroon (Tchamba et al. 1995) acknowledged that climatic variability and drought played a part in the observed impacts to floodplain habitats and wildlife populations. They estimated that in normal rainfall years the damming and irrigation schemes probably contributed less than 40 percent of the observed impacts. However, in dry years the human use of the water contributed a much larger portion of the observed impacts. Also, Tchamba et al. (1995) point out an important fact that while droughts may come and go, the dewatering schemes are permanent. This, in the long-term, could have more fundamental impacts on the wetland ecosystems than the estimated 40 percent or less on a year-to-year basis.

Anthropogenic stressors unrelated to irrigation may also complicate the evaluation of water management and ecological costs and benefits. For example, the barrage schemes on the Zambezi River may well be contributing to reductions in marine prawn harvests. However, no attempt has yet been made to determine the extent to which overfishing is also important. To what extent does overgrazing contribute to the decline in the Hadejia-Nguru wetlands? Any evaluation of the effects of irrigation must, necessarily, include the examination of the contributions by all major stressors. This has important practical applications: if the costs associated with all stressors at a site are additive, perhaps the costs that could, potentially, be incurred by irrigation could be mitigated by lessening the effects of other stressors.

4.5 Potential long-term benefits

Usually, the measurement of impacts or benefits due to irrigation project implementation ends with the project installation. However, one study shows that under some circumstances ecological benefits may accrue in the long term. Masundire (1996) documents initial impacts and long-term consequences of the Kariba Dam (built primarily for hydropower, but it also supplies agricultural needs). The creation of the Kariba Dam was preceded by an intensive effort to capture and relocate wildlife whose home ranges would be inundated by the dam. In this sense, the building of the Kariba Dam was an adverse ecological impact. However, once the area was flooded, it became an important water source for wildlife in an otherwise arid environment. Indeed, so successful has it become in attracting grazing animals and their predators during the dry season that it is now a major site for ecotourism. Thus, the Kariba Dam has been both an ecological cost and a benefit. This illustrates the difficulty in easily assigning “cost-benefit scores” on the basis of change from pre-impact conditions, without also taking into account the post-impact conditions.

4.6 Lack of quantitative data

One of the main findings of this review has been that despite the multitude of opportunities that have been presented by past irrigation schemes to provide data on activities and ecological effects, the actual data base is extremely limited. The literature that currently exists allows us to determine, at best, that adverse and beneficial effects to wetland ecosystems have occurred due to irrigation and associated activities; however, many of the questions raised in Section 3 of this review cannot be addressed. This is because few detailed and long-term studies of the costs and/or benefits of irrigation schemes have been performed in developing countries. Beyond determining that extracting or diverting too much water is likely to have deleterious effects, most existing studies do not provide information that is detailed enough to allow us to describe cause-effect linkages or to assist in avoiding future mistakes.

5. NEED FOR FURTHER RESEARCH

Important questions that remain unanswered include:

- What environmental factors affect how much water can be withdrawn for human use without unacceptable adverse ecological impacts being incurred (see Section 4.1)?
- What environmental cues (indicators) may tell us whether or not we are stressing the wetland-watershed system to the extent that significant costs may be incurred?
- In drought-prone areas, how could water resources planning be integrated with the protection of wetland ecosystems?
- While existing schemes may have caused adverse ecological impacts during their implementation, what benefits (see the Kariba Dam illustration in Section 4.2) have accrued since then, i.e., in the long term?
- How can we ensure that “small is beautiful?” Specifically, in localized and small- scale systems such as dambos we have an opportunity to merge ecological and agricultural functions. How do we do so?
- Existing data show that rice irrigation may also provide opportunities to conserve (or create) important ecological attributes. What tools and approaches can be developed that will facilitate this?

The implementation of existing irrigation projects could have provided important data to address the above questions. Yet, unfortunately, they did not do so. The reasons for this lack of follow-up are interesting as the following quote by White (1988) illustrates:

> “*To my knowledge there has not yet been a thorough, comprehensive post-audit of any major water project.*
>
> *Any such effort is impeded by factors that work in combination to discourage comprehensive study. Public criticism ... tends to narrow or muffle the study of impacts by proponents. Once the project is completed, critics lack incentives for study ... they have lost the battle and have little interest in learning that any attacks were unfounded. Proponents tend to look only for vindication ...*”

The only way in which we can redress this balance and fill important data needs is to treat future irrigation schemes as “natural experiments” that should be studied from before implementation to completion and beyond to gather data that will help us determine cause-effect relationships. Also, existing schemes should be revisited in a case-study approach to fill in some of the information gaps that should have been addressed during project planning and implementation. The IWMI proposed Comprehensive Assessment (in particular, using case studies to develop the Knowledge Base component) provides us with an opportunity to answer some of the important questions that the existing literature cannot address and begin to move forward toward more effective planning and implementation of irrigation schemes.

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APPENDIX A:

Documents Reviewed and Synopses of Findings*

* Documents are grouped by site wherever possible

Aral Sea

Aladin, et al.. 1995. The Aral Sea dessication and possible ways of rehabilitating and conserving its northern part. *Environmetrics*. 6:17–29.

- In 1992, a small earthen dam was built to contain flows in Small Aral. Breached after 9 months.
- Water level increased by more than 1 meter in 9 months.
- Salinity fell and fish extended their ranges and birds returned to the area.
- Situation reverted after the dam broke.

Kotlyakov. V.M. 1991. The Aral Sea Basin: A critical environmental zone. *Environment* 33:4–38.

- Due to diversions and dewatering of wetlands, 550,000 ha of reedswamp habitat in Amu Dar'ya delta was destroyed.
- Prior to diversions 319 bird and 70 mammal species lived and nested in Amu Dar'ya delta. 168 and 30 ,respectively, do so now.

Micklin, P.P. 1988. Desiccation of the Aral Sea: A water management disaster in the Soviet Union. *Science* 241:1170–1176.

- Prior to 1960s, deltas of two main feeder rivers were ecological oases in otherwise arid habitats, providing many services including pastureland, reeds for construction, fish harvest, etc.
- Prior to 1960s irrigation withdrawals from feeder rivers approximated 40 km^3 and area irrigated was 5 million ha. By 1987, 104 km^3 was withdrawn and 7.6 million ha were irrigated.
- Surface area and volume of Aral Sea reduced by 40 percent and 66 percent, respectively, by water diversions from Amu Dar'ya and Syr Dar'ya Rivers for irrigation.
- Salinity in remaining waterbody has increased from 10 g/L to 27g/L.
- Diversions have exposed 27,000 km^2 of salt-crusted sea bottom—little revegetation is occurring.
- Native fish species have apparently become extinct.
- Commercial fishery of 48,000 metric tones has collapsed by now.

- Area of natural lakes in Syr Dar'ya delta decreased from 500 km^2 to few tens of km^2 and 11 out of 25 largest natural lakes in Amu Dar'ya delta dried up.

- Area of riparian Tugay forest in Amu Dar'ya delta reduced by about 50 percent as depth to watertable increased by 3–8 meters.

Morimoto, Y., Morimura, A.; Ogar, N. 1997. Several landscape concepts on the Aral Sea crisis revealed by remote sensing. CERES International Symposium on Role of Remote Sensing for Environmental Issues (obtained from www.http://rosa.eni.osakafu-u.ac.jp/~yuki/aral.html).

- Some revegetation by tamarisk, salicornia, and other salt-tolerant species occurring on exposed bed of Aral Sea

Precoda, N. 1991. Requiem for the Aral Sea. *Ambio* 20:109–114.

- Prior to water diversions, an important fishery for sturgeon, carp, and bream existed, over 1 million musk rat pelts were taken annually, reeds provided raw materials for building and cardboard/paper manufacture, and Tugay riparian forest provided year-round grazing.

- Before 1960s agriculture was local in scale and confined to river valleys where moisture was abundant. This may have resulted in local loss of wetland habitat but not great reduction in water going into the Aral Sea.

- Reed-swamps that once covered 700,000 ha are now confined to about 30,000 ha close to man-made lakes.

- Withdrawal canals may be creating new wetlands (e.g., Karakum and Bolshoy Andizhansk Canals). However, these may be highly salinized.

Nile Delta

Penvenne, L.J. 1996. Disappearing delta. *American Scientist*. 84:438–439.

- Decreased sediment deposition is leading to erosion of the Nile Delta wetlands.

- Reduced sediment loads due to High Dam and trapping of sediments in delta irrigation canals.

- Irrigation of delta is causing eutrophication and contamination of wetlands.

Ramsar, 1991. Ramsar advisory missions: Report No. 26, Egypt. Lakes Bardawil and Burullus. http://ramsar.org/ram_pt_26e.htm.

- Both sites are designated as of international importance by Ramsar.

- Highly important for migratory bird populations (most of which breed in Europe).

- Sedimentation and closing off of channels connecting wetlands to sea is resulting in drying up of wetlands.

- Heavy fertilizer and pesticide loads are now entering wetlands associated with the two lakes.

- Effects on bird populations or wetland habitats are unclear as yet.

White, G.F. 1988. The environmental effects of the High Dam at Aswan. *Environment* 30:5–40.

- After closure, fish species diversity downstream of dam decreased from approximately 47 species to 14–25 species.

Hadejia-Nguru Wetlands

Adams, W.M. 1993. The wetlands and conservation. In: *The Hadejia-Nguru Wetlands: environment, economy and sustainable development of a Sahelian floodplain wetland*, G.E. Hollis,; W.M. Adams: M. Aminu-Kano (eds). Glanz, Switzerland. IUCN.

- Baturia wetland reserve within the Hadejia-Nguru wetland complex is being impacted by reduced seasonal flooding due to drought and water storage schemes.

- Vegetation (trees and shrubs) is showing signs of water stress.

- No evidence is presented that any additional ecological injury being inflicted.

Barbier, E.B.; JThompson, J.R. 1998. The value of water: Floodplain versus large-scale irrigation benefits in northern Nigeria. *Ambio* 27:434–440.

- Revenues from proposed and existing irrigation projects in Hadejia-Nguru area would recoup only 14 percent of losses due to wetland destruction.

Lemly, A.D.; Kingsford, R.T.; Thompson, J.R. 2000. Irrigated agriculture and wildlife conservation: Conflict on a global scale. *Environmental. Management*. 25:485–512.

- Prior to the construction of the dam 300-2,000 km^2 was flooded in the wet season.

- Highly important for migratory birds—320,000 numbers in 1997.

- Fifth most important wetland site for Palearctic migrant birds.

- Tiga Dam completed in 1974. Supplies water to Kano River Irrigation Project (14,000 irrigated ha). Hadejia Valley Project barrier under construction—will irrigate 8,000 ha.

- Flooding to wetlands already reduced by 17 percent.

- Seasonally flooded wetlands drying up (e.g., Baturai Wetland Reserve) and depth to groundwater increasing.

- Waterbird diversity and numbers falling, particularly cranes, storks and pelicans. No attempt made to distinguish between effects of recent droughts and water storage.

- Plans for the new dam at Kafin Zaki may reduce flows by a further 50 percent.

Pearce, F. 1992. Death of an oasis. *Audubon* May-June 1992, pp.66–74.

- Tiga dam has resulted in 50 percent loss of wetland habitat and drop in water table by 25 meters in some places.

Ramsar, 2000. Nigeria becomes the convention's 123rd contracting party. http://www.ramsar.org/w.n.nigeria_joins .htm.

- Nguru Lake and Marma Channel in Hadejia-Nguru wetlands designated site of international importance for the waterfowl and other wetland resources.

Coexitence of Irrigated Agriculture and Wetlands

De Voogt, K.; Kite, G.; Droogers, P.; Murray-Rust, H. 2000. Modeling water allocation between a wetland and irrigated agriculture in the Gediz Basin, Turkey. *Water Resources Development*, 16:639–650.

- Modeling (SLURP model) demonstrated that coexistence of important Turkish wetlands and irrigated agriculture is possible by allocating river flow to wetlands during the summer.
- Effect on agricultural yields fairly small (few percent at worst).
- Agricultural losses might be reduced further by switching to less "thirsty" crops.

Faulkner, R.D.; Lambert, R.A. 1991. The effect of irrigation on Dambo hydrology: A case study. *Journal of Hydrology* 123:147–161.

- An ecologically safe irrigation level may be 10 percent of catchment area or 30 percent of dambo area.

Lambert, R.A.; Hotchkiss, P.F.; Roberts, N.; Fualkner, R.D.; Bell, M.; Windram, A. 1990. The use of wetlands (dambos) for micro-scale irrigation in Zimbabwe. *Irrigation and Drainage Systems* 4: 17–28.

- At present 20,000 ha of dambos are cultivated in Zimbabwe.
- Also used for domestic water and livestock grazing.
- Unless over-cultivated, the use of wetland resources seems to be sustainable.

Mackel, R. 1985. Dambos and related landforms in Africa—an example for the ecological approach to tropical geomorphology. In: *Dambos: Small channelless valleys in the tropics,* M.F. Thomas; A.S. Goudie (eds). Berlin.Germany: Gebruder Borntraeger.

- Report describes morphology and vegetation of dambos.
- Typically they are areas dominated by hydrophytic vegetation amid Brachystegia or Miombo woodlands.
- The main threats to dambos are human-caused fires, overgrazing, and cultivation leading to erosion.

Masundire, H. 1996. The effects of Kariba Dam and its management on the people and ecology of the Zambezi River. In: *Water Management and Wetlands in Sub-Saharan Africa*, M.C Acreman; G.E. Hollis (eds). Glanz, Switzerland: IUCN-World Conservation Union.

- Populations of large wildlife species were displaced by flooding of their ranges during the construction of the Kariba Dam.
- The dam subsequently became an important water source for wildlife.
- The wildlife attracted to the dam in the dry season is the basis for a local ecotourism industry.

Scoones, I. 1991. Wetlands in drylands: Key resources for agriculture and pastoral production in Africa. *Ambio* 20:366–371.

- Valley bottom wetlands (fadamas, dambos, bas fonds, and wadis) comprise 5–10 percent of the land in the African savanna.
- Provide opportunities in arid areas to diversify crops, increase yields, and complement dryland farming.
- Typical management involves building small dams at head waters, berms and raised beds further down to manage water flow.
- Ecological costs of irrigation in these areas are uncertain—needs to be studied more effectively at the catchment level.

Indus Delta

Meynell, P.J.;. Qureshi, M.T. 1995. Water resource management in the Indus river delta, Pakistan. In: Acreman, M.C. & Lahmann, E. (Eds) Managing Water Resources. Parks Special Issue 5, 2, 15-23.

Water diversion schemes from the Indus are among the largest such diversions in the world. Total irrigated area covers 12 million hectares. Of total annual inflow of 180 billion m^3, 129 billion is diverted for agriculture. In dry years virtually no water reaches the delta.

The delta supported highly important ecological resources including 260,000 ha of mangrove forests. Through dewatering and sediment trapping, the diversions upstream have had the following effects on the mangroves:

- Erosion of the delta and loss of mangroves to the sea.
- Forest fragmentation.
- Replacement of mangroves by salt-tolerant species.
- Reduction in area of mangroves from 260,000 to 160,000 ha.

Australia

Kingsford, R.T.; Johnson, W. 1998. Impact of water diversions on colonially-nesting waterbirds in the Macquarie Marshes of arid Australia. *Colonial Waterbirds* 21:159–170.

- Ramsar site.
- One-hundred and thirty thousand hectares in extent.
- Dependent on flow from upstream.
- The most important wetland site for waterbirds in Australia.
- Seventy percent of flow regulated for agriculture (mainly cotton).
- Flow reaching wetlands reduced by 60 percent.
- Marshes have shrunk by 50–60 percent.
- Over 11 years, 100,000 fewer nests of storks, spoonbills, etc.
- Breeding of some species has become more irregular.

Kingsford, R.T. 2000. Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecology* 25:109–127.

Four case studies of impacts in the Murray Darling Basin:

1) Barmah-Millewa Forest and Moira Marshes.

- Ramsar site.
- Ninety thousand hectares in extent.
- Mix of rush/sedge marshes, wet grasslands, and hydrophytic woodlands.
- Dependent on water flows from the upstream.
- Annual flow into wetland reduced by about 50 percent by diversions for irrigated agriculture.
- Diversions have also shifted the main period of flooding from the spring to the summer.
- Has resulted in vegetation community alterations: those dependent on frequent flooding replaced by communities that can tolerate more arid conditions; trees are weakened and have become more vulnerable to insect attack.
- Fish, waterbird, reptile, and leech populations have decreased.

2) Chowilla Floodplain.

- Ramsar site.
- Seventeen thousand seven-hundred hectares in extent.
- Dependent on water flows from the upstream.
- Diversions for agriculture have reduced flows to wetland by >50 percent.
- The area flooded has been reduced from 33 percent of the site to 5 percent.
- Salinity has increased—killing trees in some areas.
- Biomass and abundance of aquatic invertebrates (e.g., 18 gastropod species) have declined.
- Native fish populations also have declined (no data cited).

3) Gwyder Wetlands

- Proposed for Ramsar designation.
- Twenty-four thousand hectares in extent.
- Dependent on water flows from the upstream.
- Mainly sedge/rush swamp.
- Fifty-five percent of inflow diverted for irrigated agriculture (mainly cotton).
- Cover by hydrophytic vegetation has decreased by 66 percent (converted to upland plant communities).

4) Macquarrie Marshes

- Ramsar site.
- One-hundred and thirty thousand hectares in extent.
- Dependent on the flow from the upstream.
- The most important wetland site for waterbirds in Australia.
- The dams were installed beginning in the 1960s.
- Seventy percent of the flow was regulated for agriculture (mainly cotton).
- Flow reaching wetlands reduced by 60 percent.
- Marshes have shrunk by 50–60 percent.

- Abundance and species richness of waterbirds has been reduced. Smaller colony sizes and less frequent breeding.

- Hydrophytic woodlands area reduced by 14 percent.

Logone River

Scholte, P.; de Kort, S.; van Weerd, M. 2000. Floodplain rehabilitation in Far North Cameroon: Expected impact on bird life. *Ostrich*, 71:112–117.

Tchamba, M.N.; Drijver, C.A.; Njiforti, H. 1995. The impact of flood reduction in and around the Waza National Park, Cameroon. In: Acreman, M.C. & Lahmann, E. (Eds) Managing Water Resources. Parks Special Issue 5, 2, 6-14.

Water diversions to supply large-scale irrigation schemes upriver have led to the following ecological effects downstream:

- Transformation of floodplain grasslands hitherto dominated by perennial species to communities dominated by annuals. This has meant loss of important grazing habitat for domestic livestock and for wildlife.

- Population reductions in many ungulate species including reedbuck and kob.

- Displacement of elephants into suboptimal habitat.

- An increased frequency of negative human-elephant interactions.

- Major reductions in fish populations and declines in fish catches.

Rice Production and Wetland Ecological Resources

Day, J.H.; Colwell.M.A. 1998. Water bird communities in rice fields subjected to different post-harvest treatments. *Colonial Waterbirds* 21:185–197.

- Rice fields in California Central Valley are important for migration and wintering habitat for shorebirds and the waterfowl.

- Conventional harvesting and burning creates most suitable habitat.

Lankford, B.; Franks, T. 2000. The sustainable coexistence of wetlands and rice irrigation: A case study from Tanzania. *Journal of Environment and Development*. 9:119–137.

- Coexistence of rice irrigation and wetlands is feasible if the temporal and spatial dynamics of the wetland flows are acknowledged and irrigation planning accommodates them.

- In wet years there is water for both uses. In dry years enough water must be allowed to reach wetlands to maintain core areas—irrigation may have to be cut back in dry years.

Remsen, J.V.; Swan, M.M.; Cardiff, S.W.; Rosenberg, K.V. 1991. The importance of the rice-growing areas of south-central Louisiana to winter populations of shorebirds, raptors, waders and other birds. *Journal of Louisiana Ornithoogy*. 1:37–47.

- Rice growing region supports important populations of shorebirds, waterfowls, and herons.

- Approximately 225,000 shorebirds may winter in the area making it one of the most important ornithological sites in U.S.A.

General

Bowmer, K.H.; Bales, M.; Roberts, J. 1994. Potential use of irrigation drains as wetlands. *Water Science and Technology*. 29:151–158.

- Irrigation drains, if left vegetated, may fulfill one of the functions of wetlands—water purification.

GammelsrØd, T. 1996. Effect of Zambezi River management on the prawn fishery of the Sofala Bank. In: *Water Management and Wetlands in Sub-Saharan Africa*. M.C. Acreman; G.E. Hollis (eds). Glanz, Switzerland: IUCN-World Conservation Union.

- The commercial harvest of marine prawns at the Sofala Bank, Mozambique, is positively correlated with the flow entering the sea from the Zambezi River.

- The flow from the Zambezi River has been reduced by about a factor of three due to the building of dams.

- The reduced flow has been accompanied by reductions in the prawn harvest.

Are you refereeing to bullets 4 & 5? If so, its iss better to have numbers in place of bullets. yes we could do that.

Postal Address: IWMI, P O Box 2075, Colombo, Sri Lanka **Location:** 127 Sunil Mawatha, Pelawatte, Battaramulla, Sri Lanka
Telephone: +94-11 2787404, 2784080 **Fax:** +94-11 2786854
Email: comp.assessment@cgiar.org **Website:** www.iwmi.org/assessment

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